REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-99-

0207

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE 13 Jul 99

3. Final Technical Report 1 Feb 96 to 28 Feb 99

4. TITLE AND SUBTITLE
Magnetospheric Morphology and Dynamics: Specification of the Near-Earth Operational Environment

5. FUNDING NUMBERS
F49620-96-1-0009
2311/AS
61102F

6. AUTHOR(S)
Ching-I. Meng

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Johns Hopkins University
Applied Physics Laboratory
11100 Johns Hopkins Rd
Laurel MD 20723-6099

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NM
801 N. Randolph Street, Room 732
Arlington, VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-96--0009

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Under the aegis of Air Force Office of Scientific Research (AFOSR) funding we conducted original research, for example establishing that intense aurora are suppressed by sunlight and that the solar cycle effect on intense aurora is far different than commonly supposed. Applied research has been an increasing focus, however. Recently our AFOSR research has been driven by an effort to characterize the magnetosphere. as accurately as possible -- i.e., to find and dev4op the most physically significant state variables using data available from the DMSP series satellites. These include a more sophisticated estimate of the open flux in the polar cap (the energy available for explosive release) and a proven technique for determining the first significantly stretched field line (equivalent to the Earthward edge of the current sheet) from DMSP particle precipitation data.

19990903 006

14. SUBJECT TERMS

15. NUMBER OF PAGES 12

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

FINAL TECHNICAL REPORT: AFOSR GRANT F49620-96-1-0009 "MAGNETOSPHERIC MORPHOLOGY AND DYNAMICS: SPECIFICATION OF THE NEAR-EARTH OPERATIONAL ENVIRONMENT"

Principal Investigator: Ching-I. Meng

The Johns Hopkins University Applied Physics Laboratory

Covering AFOSR sponsored research from 1996-1999

SUMMARY

Under the aegis of Air Force Office of Scientific Research (AFOSR) funding we conducted original research, for example establishing that intense aurora are suppressed by sunlight and that the solar cycle effect on intense aurora is far different than commonly supposed. Applied research has been an increasing focus, however. Recently our AFOSR research has been driven by an effort to characterize the magnetosphere as accurately as possible -- i.e., to find and develop the most physically significant state variables using data available from the DMSP series satellites. These include a more sophisticated estimate of the open flux in the polar cap (the energy available for explosive release) and a proven technique for determining the first significantly stretched field line (equivalent to the Earthward edge of the current sheet) from DMSP particle precipitation data.

I. Research Results

The DOD effort to monitor the space environment conditions is dwarfed by the NASA effort in cost, scope of effort, and numbers of spacecraft. However we have long believed that the unique features of the DMSP data set make them superior for many forms of magnetospheric research (an entertaining argument to this effect is given by *Newell and Meng*, 1995a]), and we believe, superior for monitoring current space weather conditions (nowcasting). These advantages include longevity, continuous operation, and widely dispersed identical spacecraft. The low-altitude orbits allow sampling large volumes of the magnetosphere in a short time, resulting in an ability to characterize the state of the magnetosphere which no plausible number of high-altitude spacecraft could match.

A. AFOSR Funded Basic Research 1996-1998

Figure 1 shows a result published in *Nature* which startled the community: based on 8 years of DMSP particle data, covering 4 satellites and 152,000,000 individual spectra, we found that intense electron acceleration events (discrete aurora) are much more frequent under conditions of darkness than in sunlight [*Newell et al.*, 1996b]. Although some scientists were initially skeptical, the result intrigued the community, and a number of statistical studies were conducted by other research teams. Five such additional studies have been completed, and all five research teams reach the same conclusion that we did [*Collin et al.*, 1998; *Erlandson and Zanetti*, 1998; *Kumamoto and Oya*, 1998; *Liou et al.*, 1997; and *Yamagishi et al.*, 1998]. The deluge of confirming results appearing in 1998 should shift the focus from confirming our surprising findings to explaining them.

The above research was motivated by theoretical considerations about the role of ionospheric conductivity in affecting intense discrete aurora arcs [*Atkinson*, 1970; *Lysak*, 1991]. To further test the role of ionospheric conductivity, we examine the solar cycle effect on discrete aurora. Generally it is assumed that aurora are more common at solar maximum than minimum [e.g., *Chamberlain, 1996*]. However ionizing solar UV is greatest near solar maximum, therefore ionospheric conductivity (under sunlit conditions) is highest then. Our study of the 12 years from 1984-1995 showed that the frequency of intense electron acceleration events declines linearly with increasing F10.7 number (a common proxy measure of solar UV) under sunlit conditions; thus there are fewer aurora at solar maximum than minimum. Under conditions of darkness, no correlation between F10.7 and auroral frequency was found.

The Effect of Sunlight on Intense Discrete Aurora

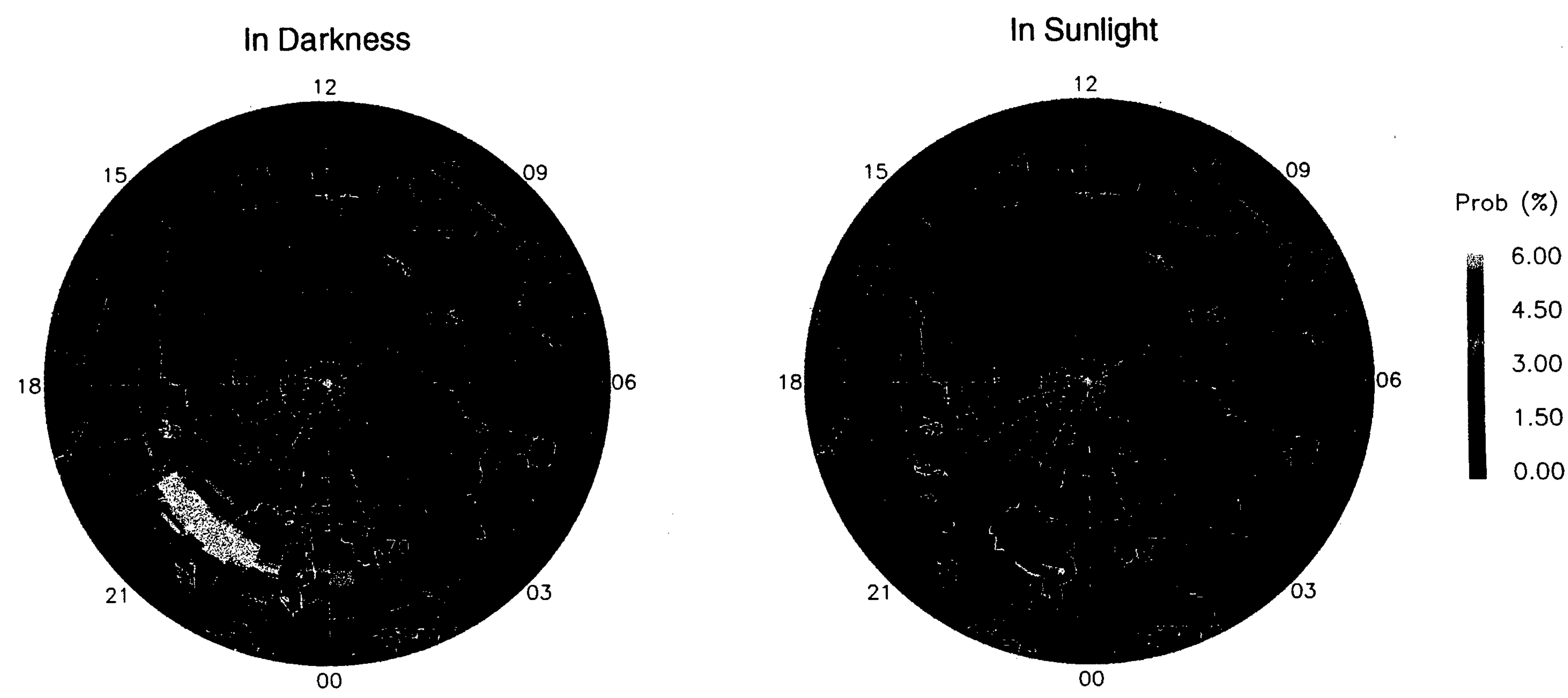


Figure 1. Intense discrete auroras occur much more frequently in darkness than in sunlight. This effect is attributed to the increase in ionospheric conductivity caused by sunlight. The above plots show the probability of observing intense discrete auroras (>5 ergs/cm^2 s) in corrected magnetic coordinates with the continental outlines shown at 06:00 UT.

B. AFOSR Funded Research with a Practical Space Weather Orientation

In order to monitor the magnetosphere from low-altitude satellites, it is necessary to determine which are the most important features to look for. A set of the most geophysically significant nightside particle precipitation boundaries was identified, along with algorithms for determining each [*Newell et al.*, 1996a]. These boundaries are: (1) The "zero-energy" convection boundary (often the plasmapause); (2e) The point where the large-scale gradient dE_e/dl switches from positive to ≤ 0 (the start of the main plasma sheet); (2i) The ion high-energy precipitation cutoff (the ion isotropy boundary or the start of the tail current sheet); (3a,b) The most equatorward and poleward electron acceleration events (spectra with "monoenergetic peaks") above 0.25 ergs/cm^2 s; (4s) Transition of electron precipitation from unstructured on a $\geq$10 km spatial scale (spectra have 0.6-0.95 correlation coefficients with neighbors) to structured precipitation (correlation coefficient usually 0.4 and below); (5) The poleward edge of the main auroral oval, marked by a spatially sharp dropoff in energy fluxes by a factor of at least 4, to levels below that typical of the auroral oval; (6) The poleward edge of the subvisual drizzle often observed poleward of the auroral oval.

Obviously crucial is the open/closed boundary, which separates field lines connected to the IMF and solar wind from those closed inside the magnetosphere. Although often assumed to be the poleward boundary of the auroral oval, our previously developed dayside [*Newell et al.*, 1991b] and nightside [*Newell et al.*, 1996a] plasma identification schemes allow for a more sophisticated approach. The correct boundary on the nightside is our "b6", the poleward limit of subvisual drizzle.

A single pass only defines one or two points along the open/closed boundary. To construct an operational system, it is necessary to know such things as, what is the

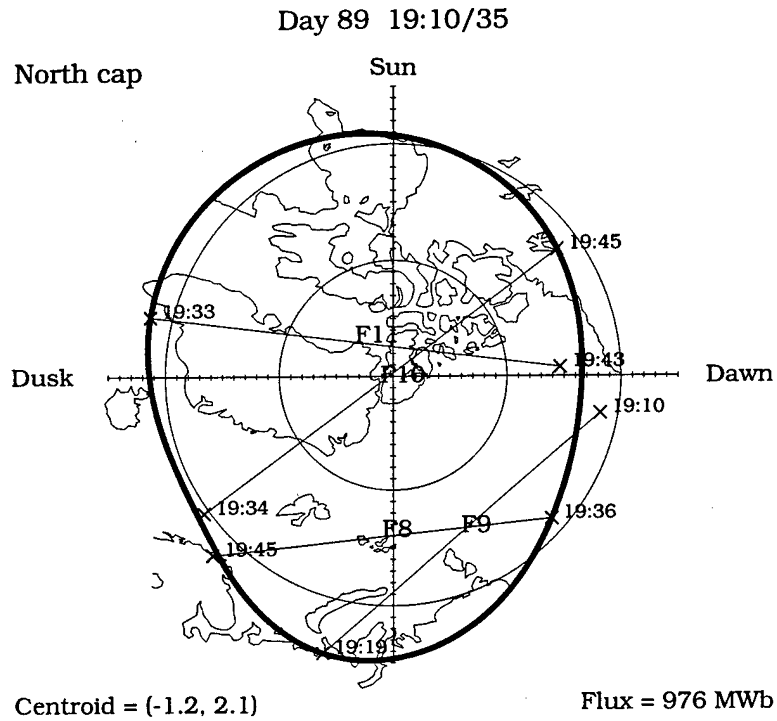


Figure 2. A cubic spline approximation to the open–closed boundary. Eight boundary crossings were observed during a 35 minute interval by DMSP F8-11 on day 89 of 1992. For crossings that are close together in MLT the spline is drawn through their average position. The concentric circles are 70° and 80° corrected magnetic latitude and the centroid is given as (x, y) where the x axis points toward the Sun and the y axis toward dusk.

uncertainty (standard error) in using a one point (or *n*-point) fit to the open/closed boundary?

We researched fits to the open/closed boundary [*Sotirelis et al.*, 1998]. In particular, a flexible algorithm for making an n-point fit to this boundary was developed, using a polynomial expansion in local time and radius. We took advantage of a brief interval when 4 DMSP satellites were simultaneously returning SSJ/4 particle data to test the effects of varying the number of boundary crossings on the inferred open/closed flux. Figure 2 illustrates a sample case when 8 crossings of one polar cap occur within 50 minutes (4 satellites x 2 points per satellite). A subroutine uses a model magnetic field to integrate the open flux enclosed within the boundary, returned in megawebers. The fit can be done using a subset (say 1-4 points) of the data then compared to the full curve fitting using all 8 points.

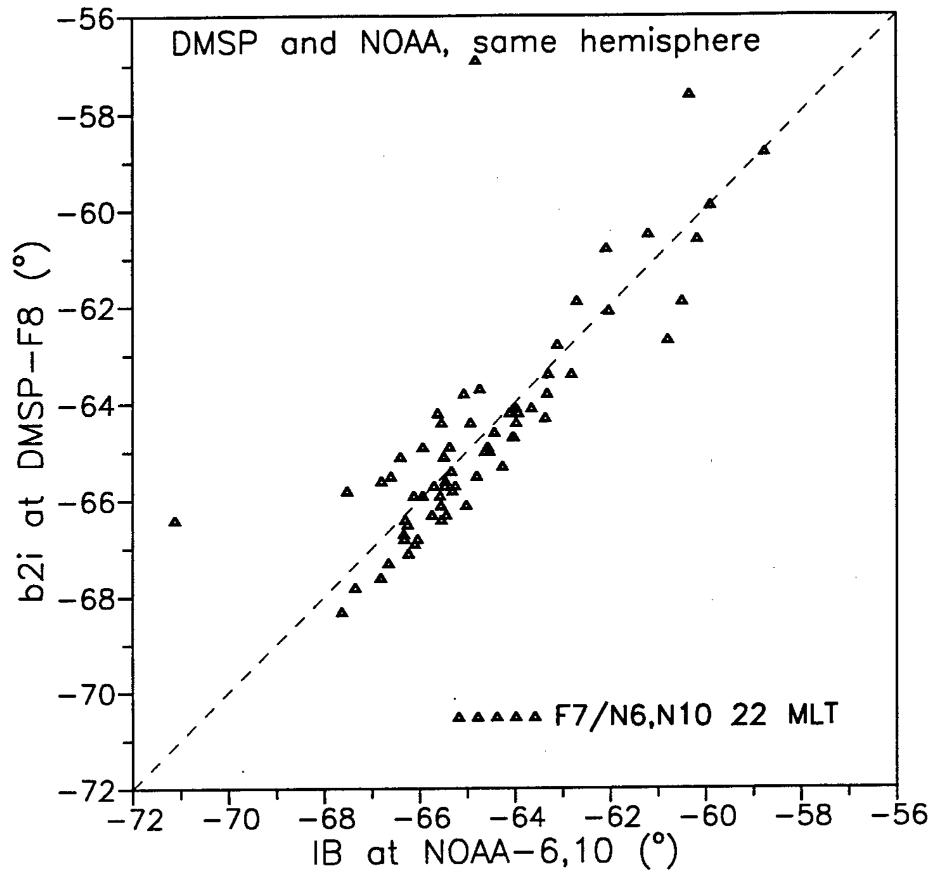
Some of the key results from this research [*Sotirelis et al.*, 1998]. are that a single open/closed boundary point specifies the open flux with a standard deviation of about 33%, probably too large for many quantitative purposes. However a 2-point fit reduces the uncertainty to only ~20%, while a four-point fit should be more than adequate for space physics research purposes.

Of course it is rare to have 4 DMSP satellites operational. However there have also generally been 2 NOAA satellites in operation. We have acquired the NOAA data set to supplement the DMSP observations for a global magnetospheric specification project. Using these 4-6 satellites it should be possible to construct a time history of the magnetosphere with unprecedented accuracy. Since all aspects of the work are fully automated, this approach lends itself to Air Force operational purposes.

A second boundary of great geophysical significance is the isotropy boundary/ion precipitation maximum (IB/b2i). It has been shown in recent years that the high-energy ion equatorward precipitation cutoff (which is also the precipitating ion energy flux maximum) is a good proxy for where the magnetic field lines begin to be significantly stretched. It is probably the best and most direct proxy for the location of the Earthward edge of the current sheet. Poleward of the precipitation boundary at any particular energy, the ions are highly isotropic [*Sergeev et al.*, 1993]. The physical mechanism is quite simple: ions cannot maintain pitch angle while bending around field lines which have a radius of curvature comparable to the ion gyroradi. On dipolar field lines, pitch angle scattering ceases, the loss cone empties, and precipitation ceases.

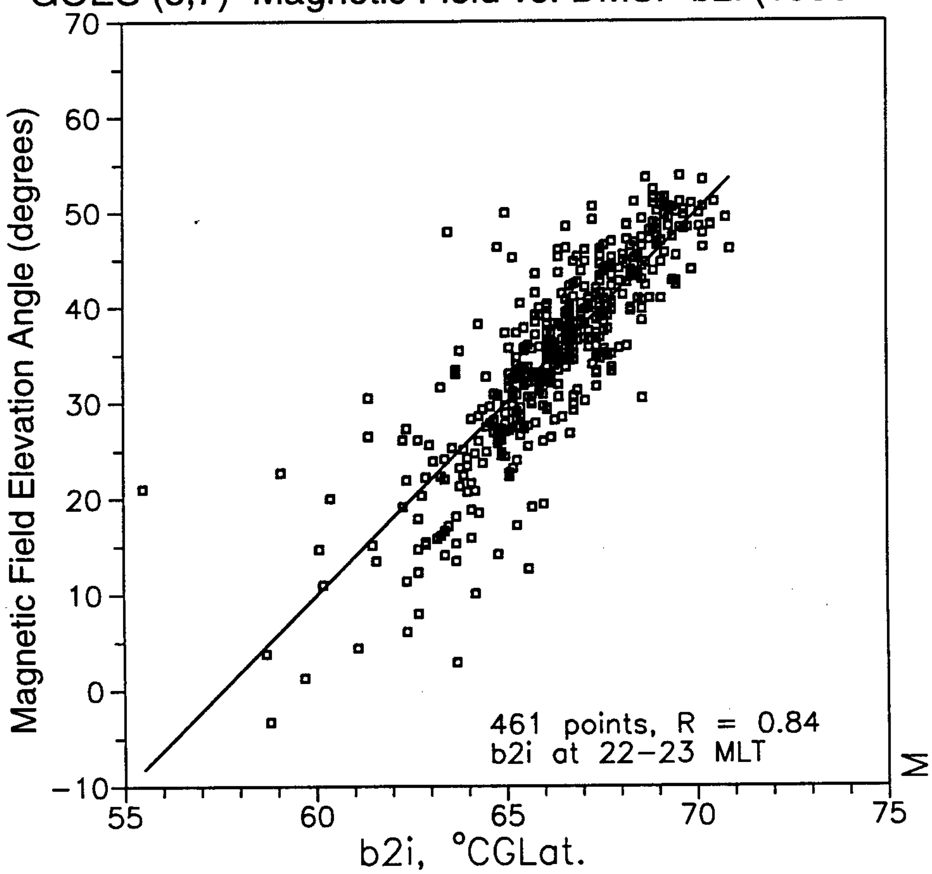
Work funded by this AFOSR grant has dramatically verified the practicality of monitoring the state of the magnetotail in this way [*Newell et al.*, 1998a]. In particular it was directly demonstrated that the b2i boundary determined by DMSP predicts the geosynchronous magnetic field tilt angle (stretching) as measured by GOES magnetometers to a high degree of accuracy. These results can been seen in Figure 3.

Figure 3. Evidence that the DMSP b2i boundary characterizes the magnetosphere.



DMSP b2i agrees well with NOAA isotropy boundary

GOES (5,7) Magnetic Field vs. DMSP b2i (1986-1987)



DMSP b2i predicts geo-synchronous magnetic field elevation

II. REFERENCES

(Note: there is a separate bibliography of publications supported by AFOSR Grant F49620-96-1-0009 over the period 1996-1998).

Atkinson, G., Auroral arcs: result of the interaction of a dynamic magnetosphere with the ionosphere, J. Geophys. Res., 75, 4746, 1970.

Chamberlain, J. W., *The Physics of Aurora and Airglow,* American Geophysical Union (reprinted), 1996.

Collin, H. L., W. K. Peterson, O. W. Lennartsson, J. F. Drake, The seasonal variation of auroral ion beams, *Geophys. Res. Lett., 25,* 4071, 1998.

Erlandson, R. E., and L. J. Zanetti, A statistical study of auroral electromagnetic ion cyclotron waves, J. Geophys. Res., 103, 4627, 1998.

Fujii, R., T. Iijima, T. A. Potemra, The amplitude of field-aligned currents at north high latitudes observed by Triad, *J. Geophys. Res., 78,* 6802, 1981.

Kumamoto, A., and H. Oya, Asymmetry of occurence-frequency and intensity of AKR between summer polar region and winter polar region sources, *Geophys. Res. Lett., 25,* 2369, 1998.

Liou, K., P. T. Newell, C.-I. Meng, M. Brittnacher, and G. Parks, Synoptic auroral distribution: A survey using Polar ultraviolet imagery, *J. Geophys. Res., 102,* 27197, 1997.

Lyons, L. R., and T. W. Speiser, Evidence for current sheet acceleration in the geomagnetic tail, *J. Geophys. Res., 87,* 2276, 1982.

Mayaud, P. N., Derivation, *Meaning, and Use of Geomagnetic Indices*, Geophysical monograph 22, American Geophysical Union, 1980.

Newell, P. T., and C.-I. Meng, Magnetopause dynamics as inferred from plasma measurements on low-altitude satellites, *Physics of the Magnetopause,* P. Song and B. U. O. Sonnerup editors, AGU Monograph 90, 407-416, 1995.

Newell, P.T., Y.I. Feldstein, Y.I. Galperin, and C.-I. Meng, The morphology of nightside precipitation, *J. Geophys. Res.,101,* 10737-10748, 1996a.

Newell, P. T., C.-I. Meng, and K. M. Lyons, Discrete aurorae are suppressed in sunlight, *Nature, 381,* 766, 1996b.

Newell, P.T., D. Xu, C.-I. Meng, and M.G. Kivelson, Dynamical polar cap: A unifying approach, *J. Geophys. Res., 102,* 127, 1997.

Newell, P. T., V. A. Sergeev, G. R. Bikkuzina, and S. Wing, Characterizing the state of the magnetosphere: testing the ion precipitation maxima latitude (b2i) and the ion isotropy boundary, *J. Geophys. Res., 103,* 4739, 1998a.

Newell, P. T., C.-I. Meng, and S. Wing, Relation to solar activity of intense aurorae in sunlight and darkness, *Nature, 393,* 342, 1998b.

Sergeev, V. A., E. M. Sazhina, N. A. Tsyganenko, J. A. Lundblad, and F. Soraas, Pitch-angle scattering of energetic protons in the magnetotail current sheet as the dominant source of their isotropic precipitation in the nightside ionosphere, *Planet. Space Sci., 31,* 1147, 1983.

Sotirelis, T., P. T. Newell, and C.-I. Meng, Polar rain as a diagnostic of recent rapid dayside merging, *J. Geophys. Res.*, 102, 7151-7157, 1997.

Yamagishi, H., Y. Fujita, N. Sato, P. Stauning, M. Nishino, and K. Makita, Conjugate features of auroras observed by TV cameras and imaging riometers at auroral zone and polar cap conjugate-pair stations, in *Polar Cap Boundary Phenomena*, edited by J. Moen, A. Egeland, and M. Lockwood, Kluwer Academic Publishers, Dordrecht, 1998.

III. AFOSR Grant F49620-92-J-0196 Supported Publications (1996-1998)

1996

1. Hones, E. W., M. F. Thomsen, G. D. Reeves, L. A. Weiss, D. J. McComas, and P. T. Newell, Observational determination of magnetic connectivity of the geosynchronous region of the magnetosphere to the auroral oval, *J. Geophys. Res., 101,* 2629-2640, 1996.
2. Kan, J. R., C. S. Deehr, L. H. Lyu, and P. T. Newell, Ionospheric signatures of patchy-intermittent reconnection at dayside magnetopause, *J. Geophys. Res., 101,* 10939-10945, 1996.
3. Newell, P. T., K. M. Lyons, and C.-I. Meng, A large survey of electron acceleration events, *J. Geophys. Res., 101,* 2599-2614, 1996.
4. Newell, P. T., Y. I. Feldstein, Yu. I. Galperin, and C.-I. Meng, The morphology of nightside precipitation, *J. Geophys. Res., 101,* 10737-10748 1996.
5. Newell, P. T., and D. G. Sibeck, Transient versus quasi-steady merging: which describes the important physics?, *Eos* (invited debate) 246, 1996.

92. Newell, P. T., C.-I. Meng, and K. M. Lyons, Discrete aurorae are suppressed in sunlight, *Nature, 381,* 766-767, 1996.

6. Ohtani, S., L. G. Blomberg, P. T. Newell, M. Yamauchi, T. A. Potemra, and L. J. Zanetti, Altitudinal comparison of dayside field-aligned current signatures by Viking and DMSP-F7: intermediate-scale field-aligned current systems, *J. Geophys. Res., 101,* 15297-15310, 1996.
7. Sibeck, D. G., and P. T. Newell, Reply, *J. Geophys. Res., 101,* 13351-13352, 1996.

95. Troshichev, O. A., E. M. Shishkina, C.-I. Meng, and P. T. Newell, Identification of the poleward boundary of the auroral oval using characteristics of ion precipitation, *J. Geophys. Res., 101,* 5035-5046, 1996.

8. Wing, S., P. T. Newell, and T. G. Onsager, Modeling the entry of magnetosheath electrons into the dayside ionosphere, *J. Geophys. Res., 101,* 13155-13167, 1996.
9. Yamamoto, T., S. Inoue, N. Nishitani, M. Ozaki, and C.-I. Meng, A theory for generation of the paired region 1 and region 2 field-aligned currents, *J. Geophys. Res., 101,* 27199-27222, 1996.

1997

10. Dryud, L. P., M. J. Engebretson, J. L. Posch, W. J. Hughes, H. Fukunishi, R. L. Arnoldy, P. T. Newell, and R. B. Horne, Ground observations and possible source regions of two types of Pc 1-2 micropulsations at very high latitudes, *J. Geophys. Res., 102,* 27011-27028, 1997.
11. Liou, K., P. T. Newell, C.-I. Meng, A. T. Y. Lui, M. Brittnacher, and G. Parks, Dayside auroral activity as a possible precursor of substorm onsets: a survey using POLAR UVI imagery, *J. Geophys. Res., 102,* 19835-19844, 1997.
12. Liou, K., P. T. Newell, C.-I. Meng, M. Brittnacher, and G. Parks, Synoptic auroral distribution: A survey using Polar ultraviolet imagery, *J. Geophys. Res., 102,* 27197-27205, 1997.
13. Newell, P. T., Xu, D., C-I. Meng, and M. G. Kivelson, The dynamical polar cap: a unifying approach, *J. Geophys. Res., 102,* 127-139, 1997.
14. Schiffler, A., G. Sofko, P. T. Newell, and R. A. Greenwald, Mapping the outer LLBL with SuperDARN double-peaked spectra, *Geophys. Res. Lett.,24,* 3149-3152, 1997.
15. Sergeev, V. A., G. R. Bikkuzina, and P. T. Newell, Dayside isotropic precipitation of energetic protons, *Annales Geophys., 15,* 1233-1245, 1997.
16. Sotirelis, T., P. T. Newell, and C.-I. Meng, Polar rain as a diagnostic of rapid dayside merging, *J. Geophys. Res. 102,* 7151-7157, 1997.
17. Yahnin, A. G., V. G. Vorobjev, T. Bösinger, R. Rasinkangas, D. G. Sibeck, and P. T. Newell, On the source region of traveling convection vortices, *Geophys. Res. Lett., 24,* 237-240, 1997.

1998

18. Kauristie, K., J. Weygand, T. I. Pulkkinen, J. S. Murphree, and P. T. Newell, Size of the auroral oval: UV-ovals and precipitation boundaries compared, (in press) *J. Geophys. Res.*, 1998.

19. Liou, K., P. T. Newell, C.-I. Meng, M. Brittnacher, and G. Parks, Characteristics of the solar wind controlled auroral emissions, *J. Geophys. Res., 103,* 17543-17557, 1998.
20. Liou, K., C.-I. Meng, A. T. Y. Lui, P. T. Newell, M. Nosé, M. Brittnacher, and G. Parks, A fresh look at substorm onset identifiers, submitted to the proceedings of the Fourth International Conference on Substorms, Hamana, Japan, 1998.
21. Lui, A. T. Y., K. Liou, P. T. Newell, C.-I. Meng, S.-I. Ohtani, T. Mukai, T. Yamamoto, T. Ogino, S. Kokubun, M. J. Brittnacher, and G. K. Parks, Plasma sheet behavior associated with auroral breakups, submitted to the proceedings of the Fourth International Conference on Substorms, Hamana, Japan, 1998.
22. Lui, A. T. Y., D. J. Williams, R. W. McEntire, S. Ohtani, L. J. Zanetti, W. A. Bristow, R. A. Greenwald, P. T. Newell, S. P. Christon, T. Mukai, K. Tsuruda, T. Yamamoto, S. Kokubun, H. Matsumoto, H. Kojima, T. Murata, D. H. Fairfield, R. P. Lepping, J. C. Samson, G. Rostoker, G. D. Reeves, A. L. Rodger, and H. J. Singer, Multipoint study of a substorm on February 9, 1995, *J. Geophys. Res., 103,* 17333-17343, 1998.
23. Newell, P. T., and S. Wing, Entry of solar wind plasma into the magnetosphere: observations encounter simulation, *Geospace Mass and Energy Flow: Results from the ISTP Program,* Geophys. Mono. 104, 73-84, American Geophysical Union, 1998.
24. Newell, P. T., V. A. Sergeev, G. R. Bikkuzina, and S. Wing, Characterizing the state of the magnetosphere: testing the ion precipitation maxima latitude (b2i) and the ion isotropy boundary, *J. Geophys. Res., 103,* 4739-4745, 1998.
25. Newell, P. T., and C.-I. Meng, Open and closed low latitude boundary layer, 91-101, in *Polar Cap Boundary Phenomena,* J. Moen et al. editors, Kluwer Publisher, Dordrecht, 1998.
26. Newell, P. T., C.-I. Meng and S. Wing, Relation to solar activity of intense aurorae in sunlight and darkness, *Nature, 393,* 342-344, 1998.
27. Newell, P. T., K. Liou, C.-I. Meng, M. J. Brittnacher, and G. Parks, Dynamics of double-theta aurora: Polar UVI study of January 10-11, 1998, (in press) *J. Geophys. Res.,* 1998.
28. Sotirelis, T., P. T. Newell, and C.-I. Meng, The shape of the open-closed boundary of the polar cap as determined from observations of precipitating particles by up to four DMSP satellites, *J. Geophys. Res. 103,* 399-406, 1998.
29. Newell, P. T., K. Liou, S. Wing, and C.-I. Meng, Ionospheric conductivity and the formation of auroral arcs: a review with an emphasis on solar cycle effects, submitted to the proceedings of the Fourth International Conference on Substorms, Hamana, Japan, 1998.
30. Newell, P. T., New results confirm the importance of the ionosphere in space weather, submitted to *EOS,* (invited review), 1998.
31. Sergeev, V. A., K. Liou, C.-I. Meng, P. T. Newell, M. Brittnacher, G. Parks, and G. D. Reeves, Development of auroral streamers in association with localized impulsive injections to the inner magnetotail, to be submitted to *Geophys. Res. Lett.,* 1998.
32. Sergeev, V. A., L. I. Vagina, K. Kauristie, H. Koskinen, A. Huuskonen, A. Pajunpaa, R. Pellinen, T. Phan, V. Angelopoulos, R. P. Lin, R. P. Lepping, G. D. Reeves, and P. T. Newell, Continuous activity and substorm activations during a weak magnetic storm (WIND tail passage), submitted to the proceedings of the Fourth International Conference on Substorms, Hamana, Japan, 1998.
33. Watanabe, M., T. Iijima, M. Nakagawa, T. A. Potemra, L. J. Zanetti, S.-I. Ohtani, and P. T. Newell, Field-aligned current systems in the magnetospheric ground state, *J. Geophys. Res., 103,* 6853-6869, 1998.
34. Wing, S., and P. T. Newell, Central plasma sheet ion properties as inferred from ionospheric observations, *J. Geophys. Res., 103,* 6785-6800, 1998.

IV. LIST OF GRADUATE STUDENT AND POSTDOCTORAL SCHOLARS SPONSORED BY THE PI OR CLOSELY COLLOBORATED WITH OVER THE PAST 5 YEARS

T. Sotirelis
K. Liou
S. Wing
K. Kauristie
J. Minow
E.R. Sanchez
D. Xu